On the Effectiveness of Control-Flow Integrity in Practice

Lucas Becker, Jiska Classen, Matthias Hollick

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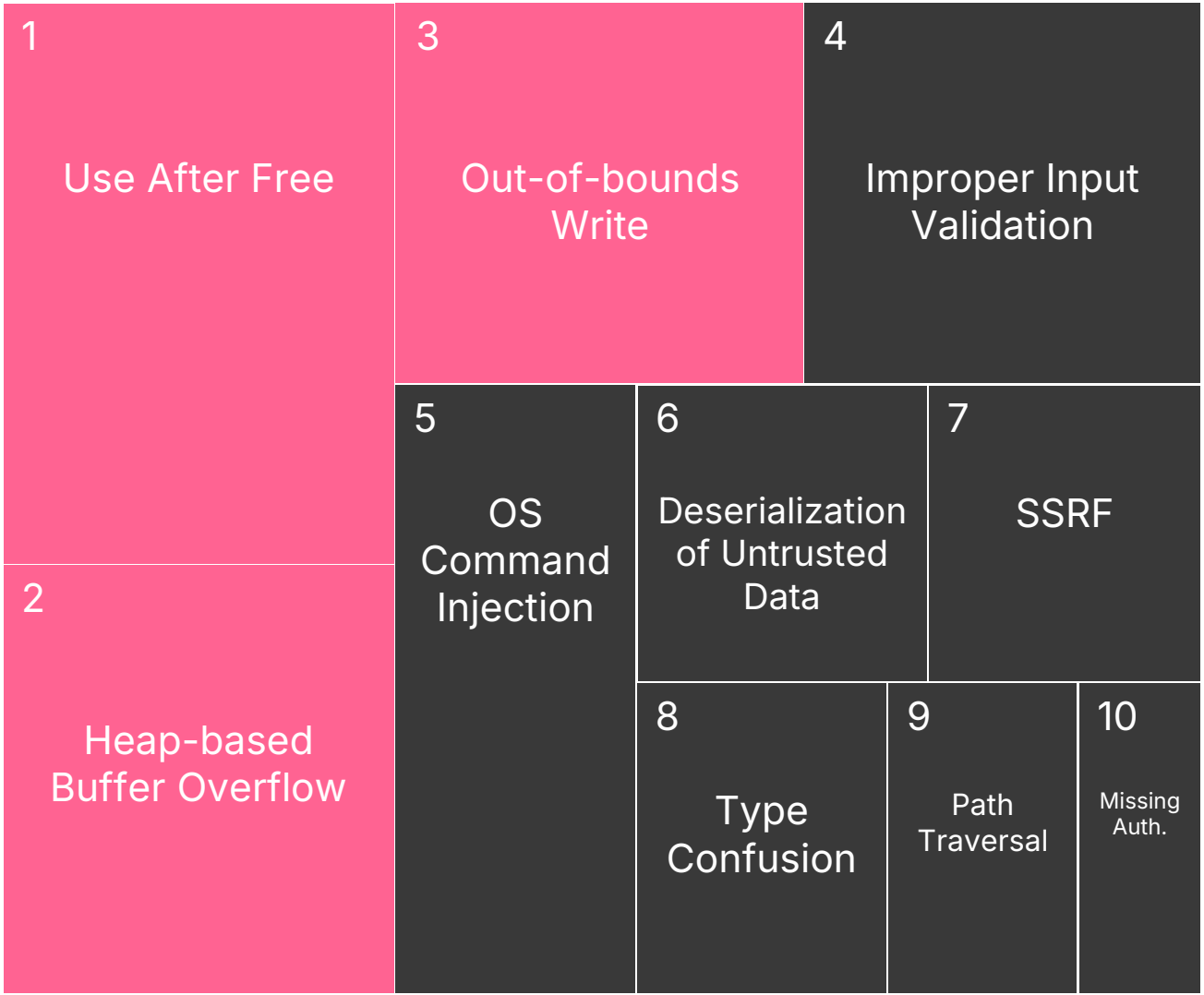
Why Control-Flow Integrity (CFI)?

“Memory Corruption Is a Solved Problem”

Why CFI?

MITRE
TOP 10 KEV 2023

46%



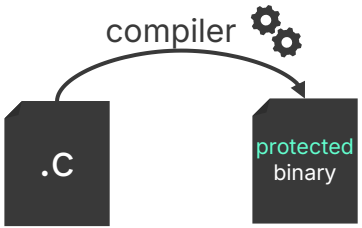
[1]

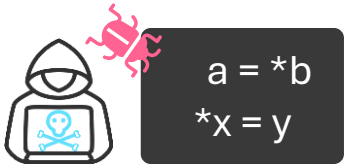
Why CFI?

“Memory Corruption Is a ~~Solved~~ Persistent Problem”

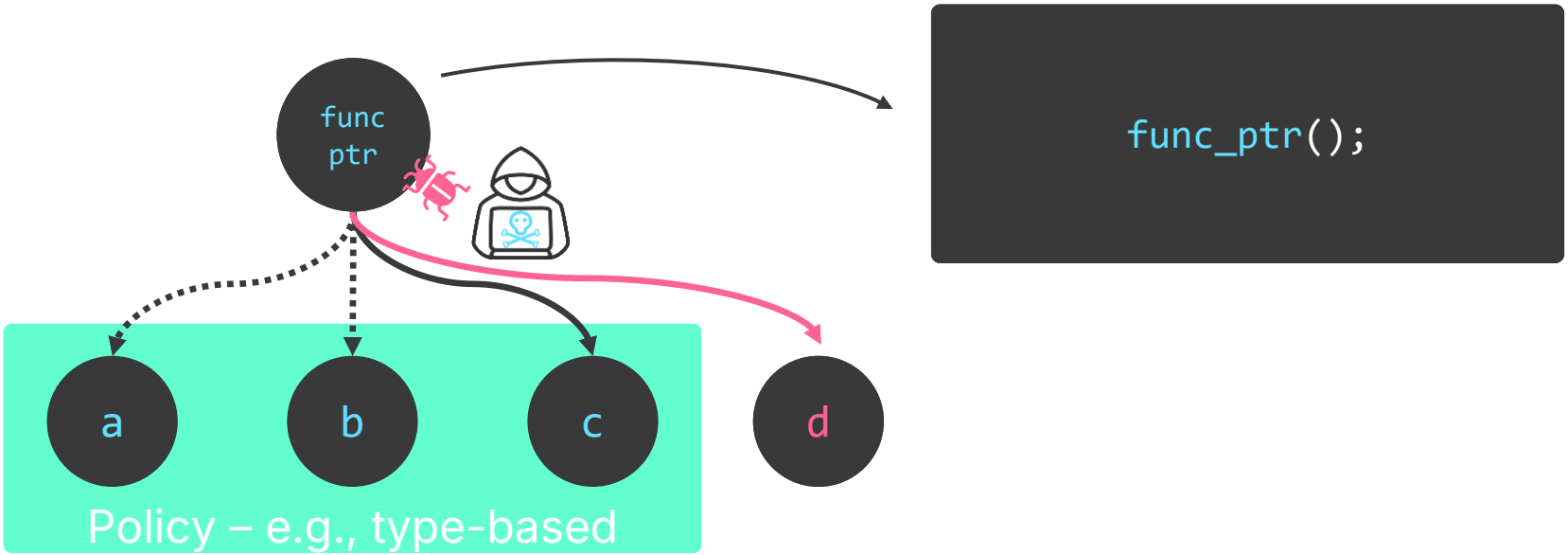
CFI as a Solution

CFI: Prevents exploitation of memory safety bugs
by inhibiting control-flow deviations

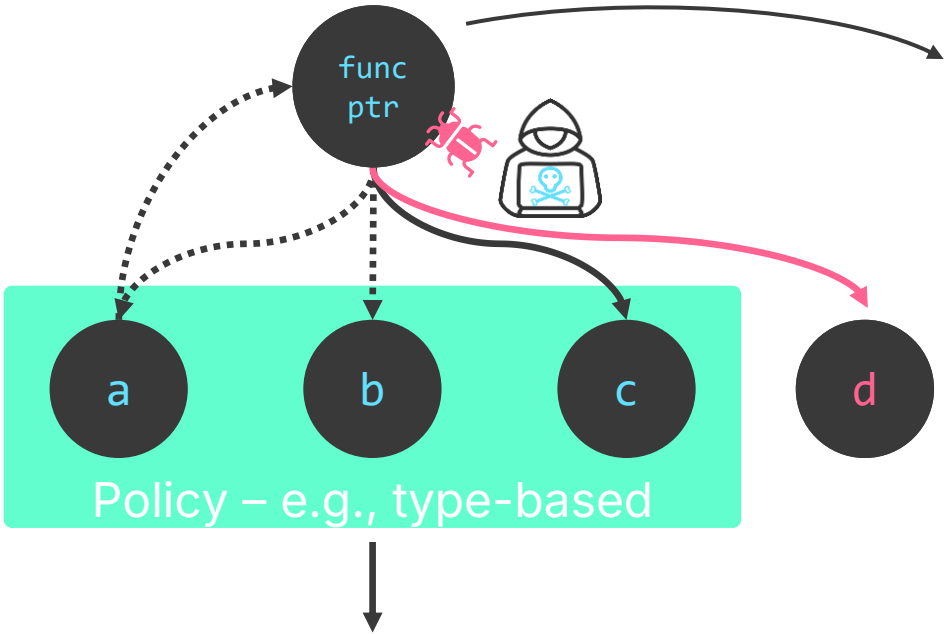




How CFI Works



How CFI Works



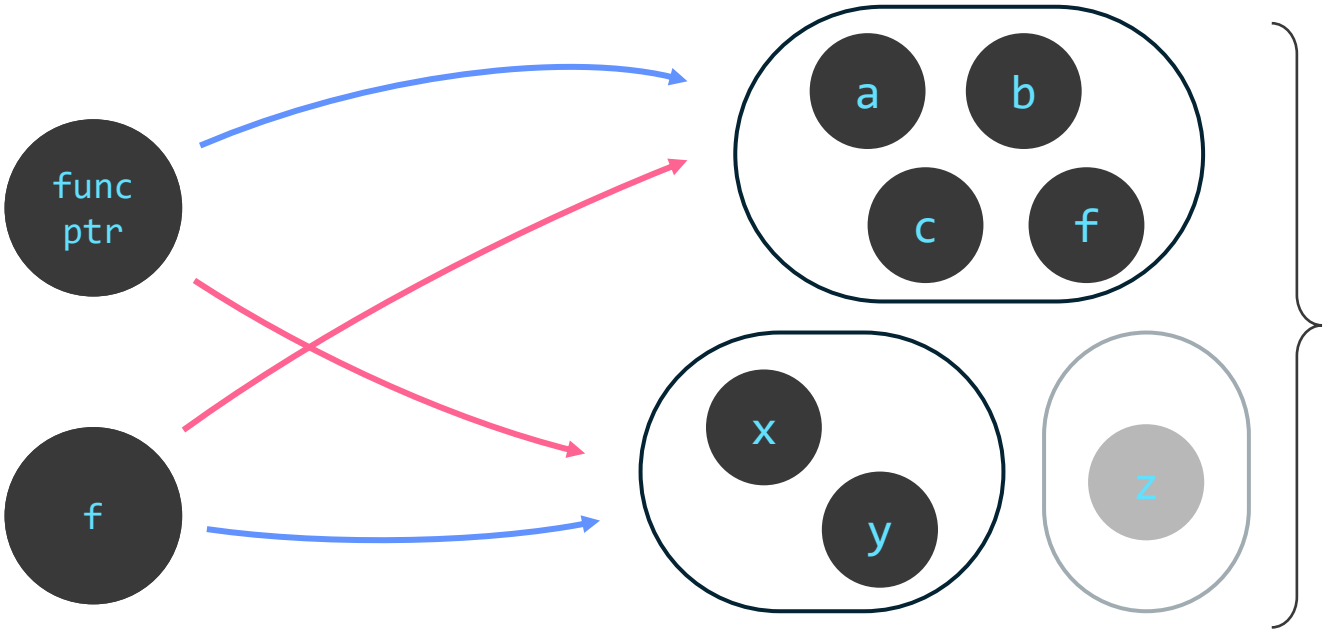

```
if (!InlinedFastCheck(
                    func_ptr))
   __cfi_slowpath(typeID,
                    func_ptr);
func_ptr();
```

```
__cfi_check(
        typeID,
        func_ptr);


      module
```

Control-flow Integrity + (Shadow Stack)

Equivalence Classes

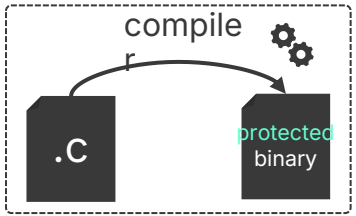


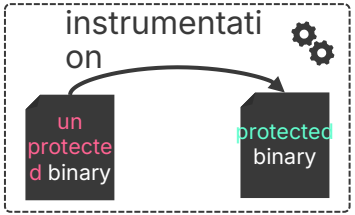
#EC fixed
↓
coarse grained

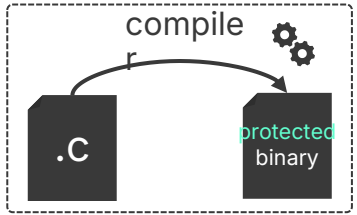
#EC program dependent
↓
fine grained

Academia vs. Industry

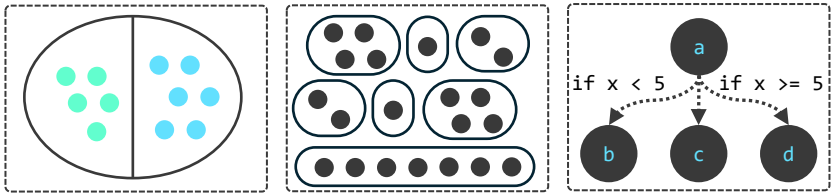
Approaches?

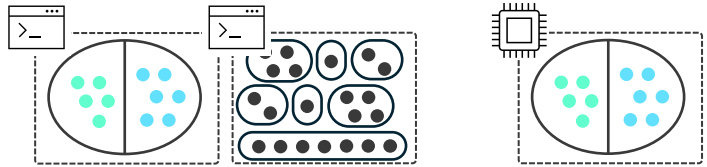






Granularity?





→ Academic schemes promising, but not (often) adopted

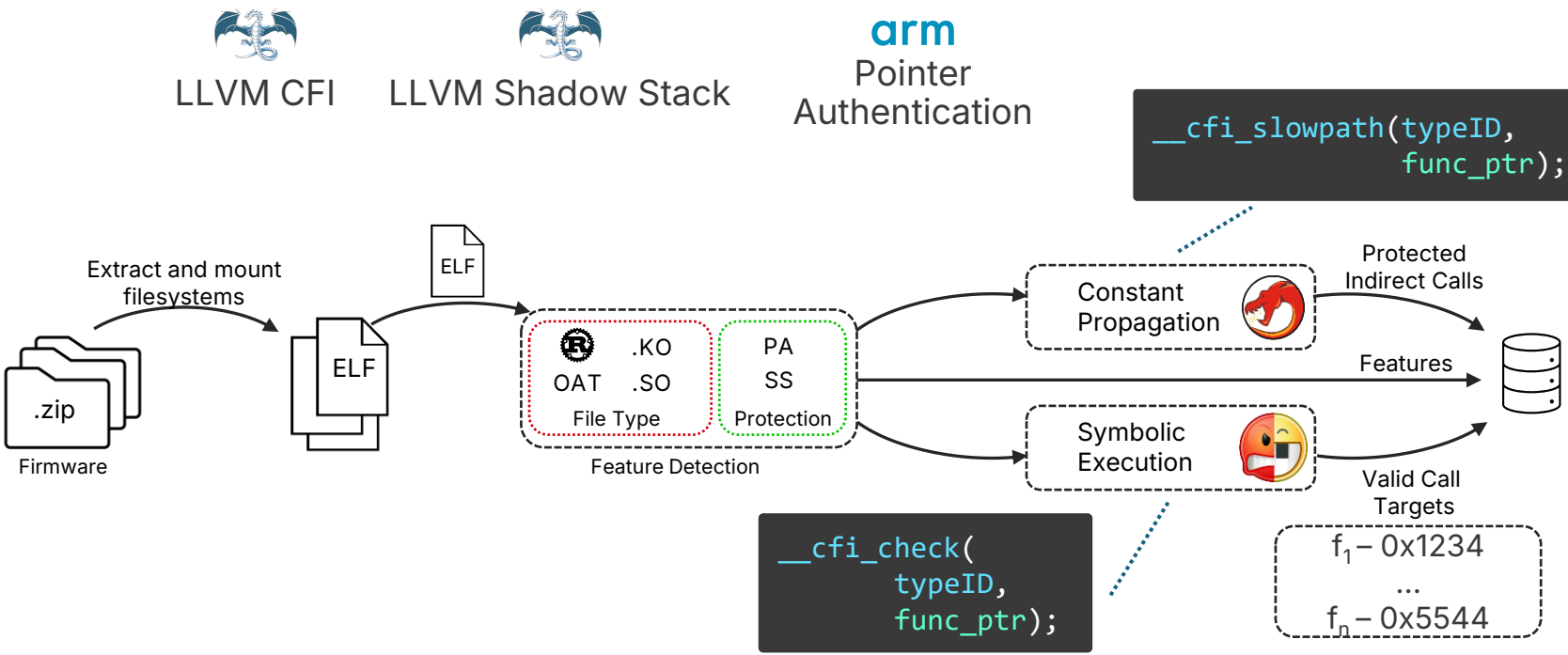
A Closer Look on CFI on Android

Supports a combination of different schemes

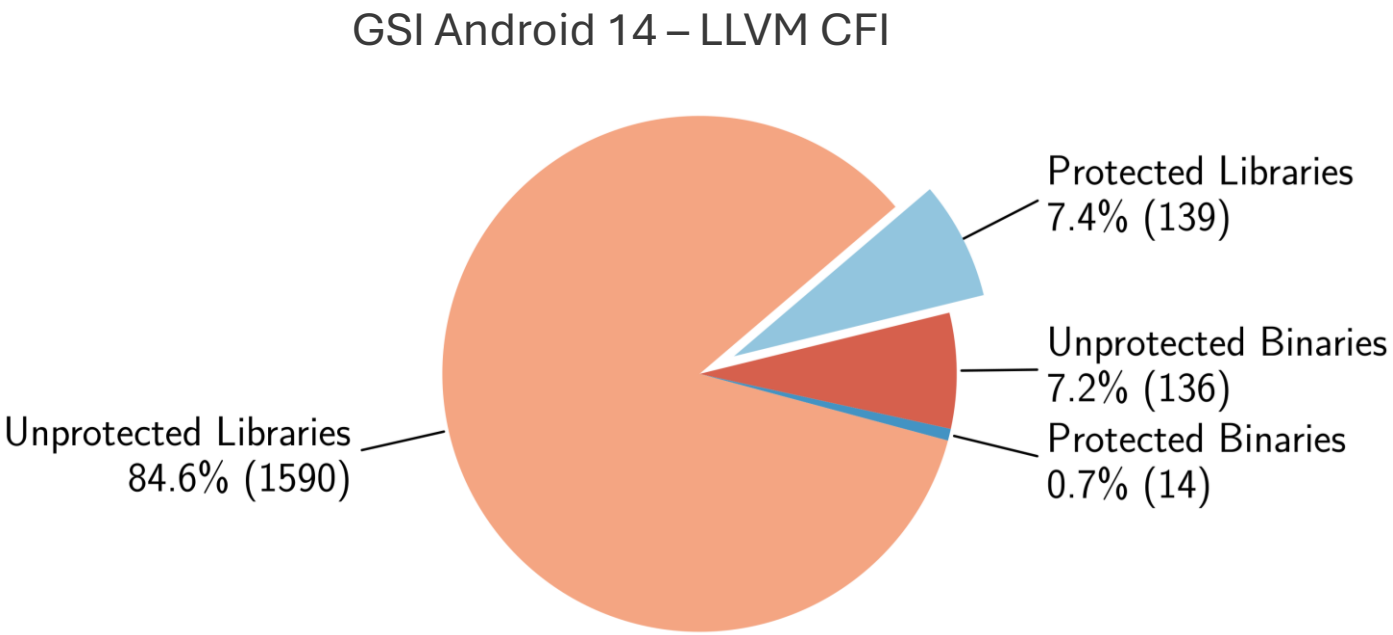
LLVM CFI

LLVM Shadow Stack

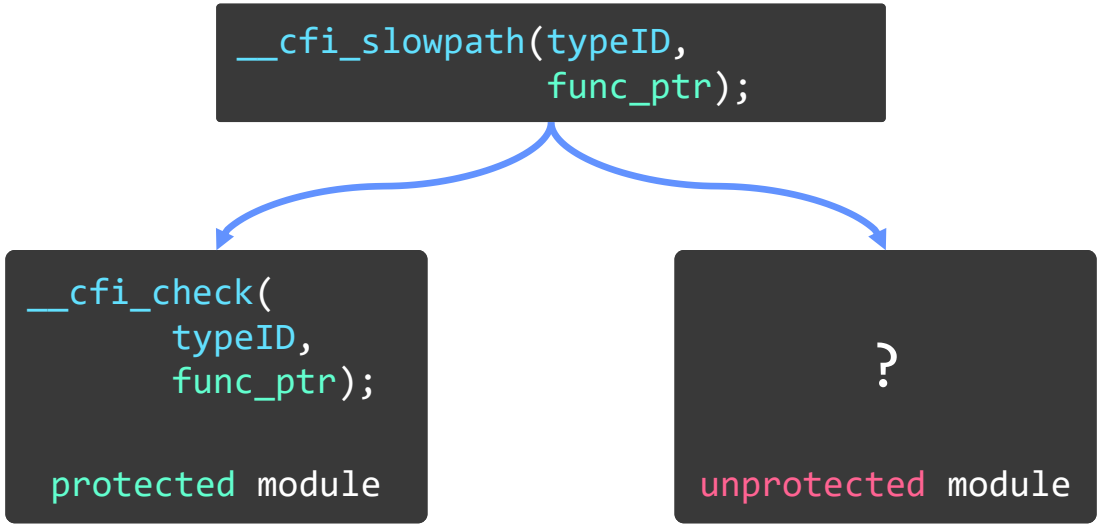
arm Pointer Authentication



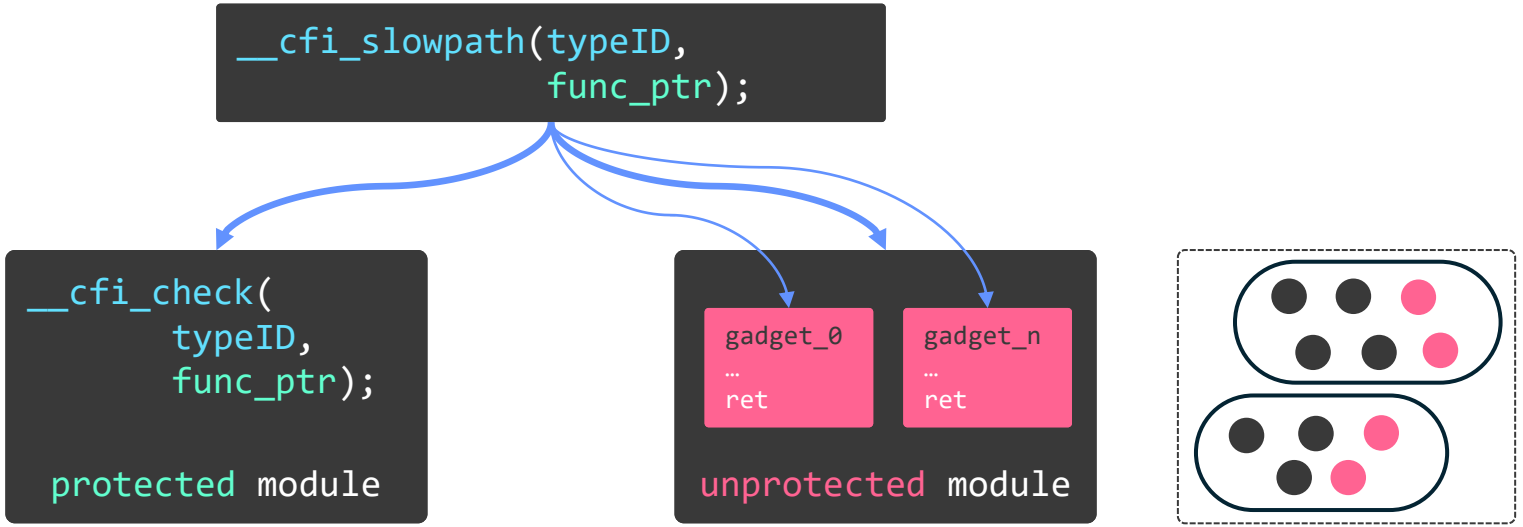
Android CFI Coverage



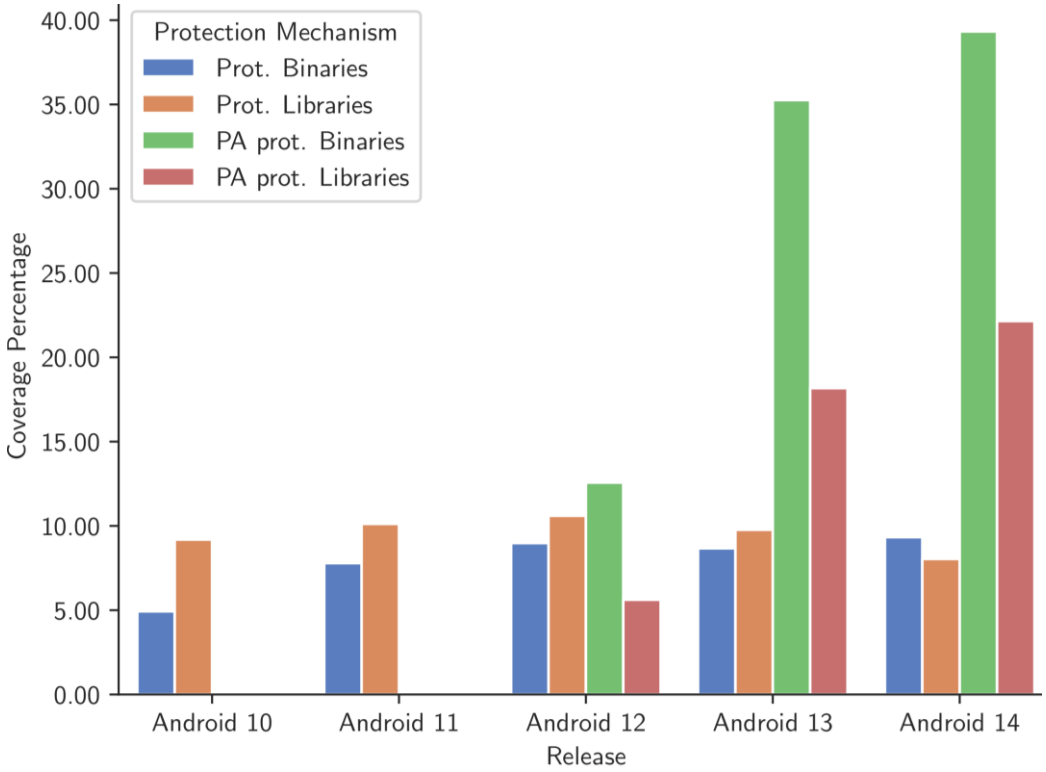
Unprotected Modules in LLVM CFI



Unprotected Modules in LLVM CFI



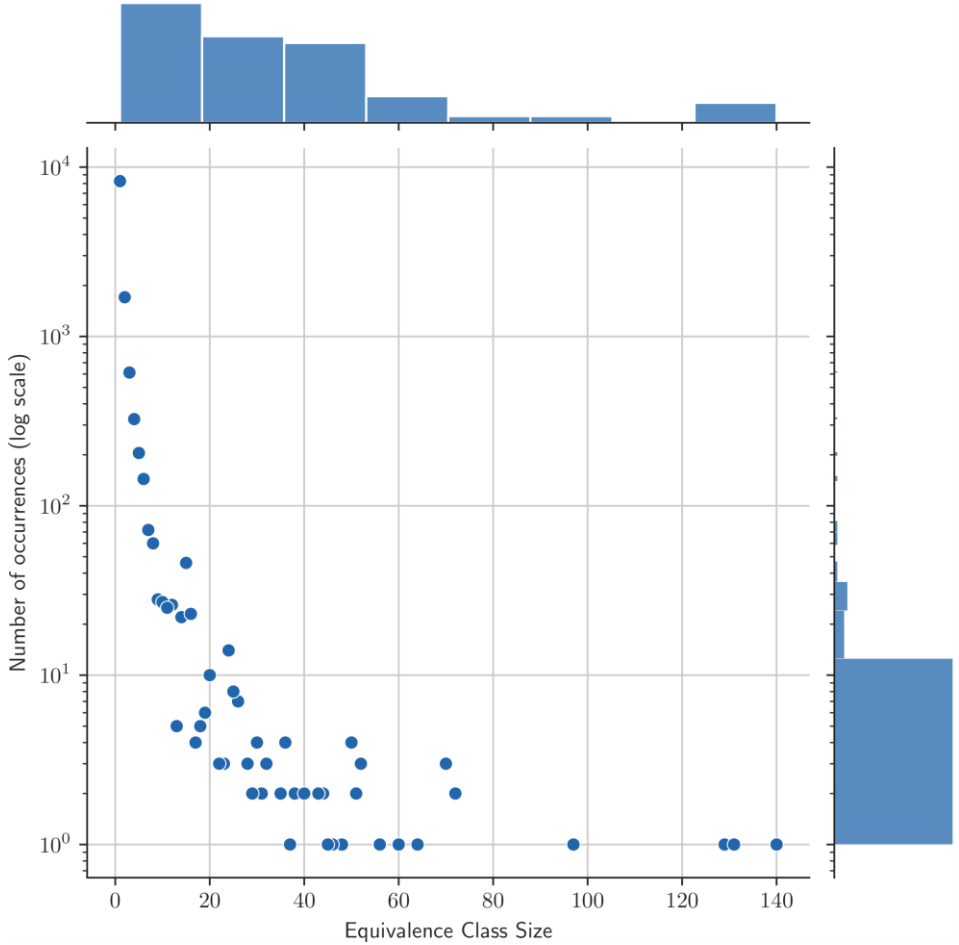
Android CFI Coverage – Over Time



Equivalence Class Size Distribution

GSI 14

Binaries & Shared Objects
(no dependencies)

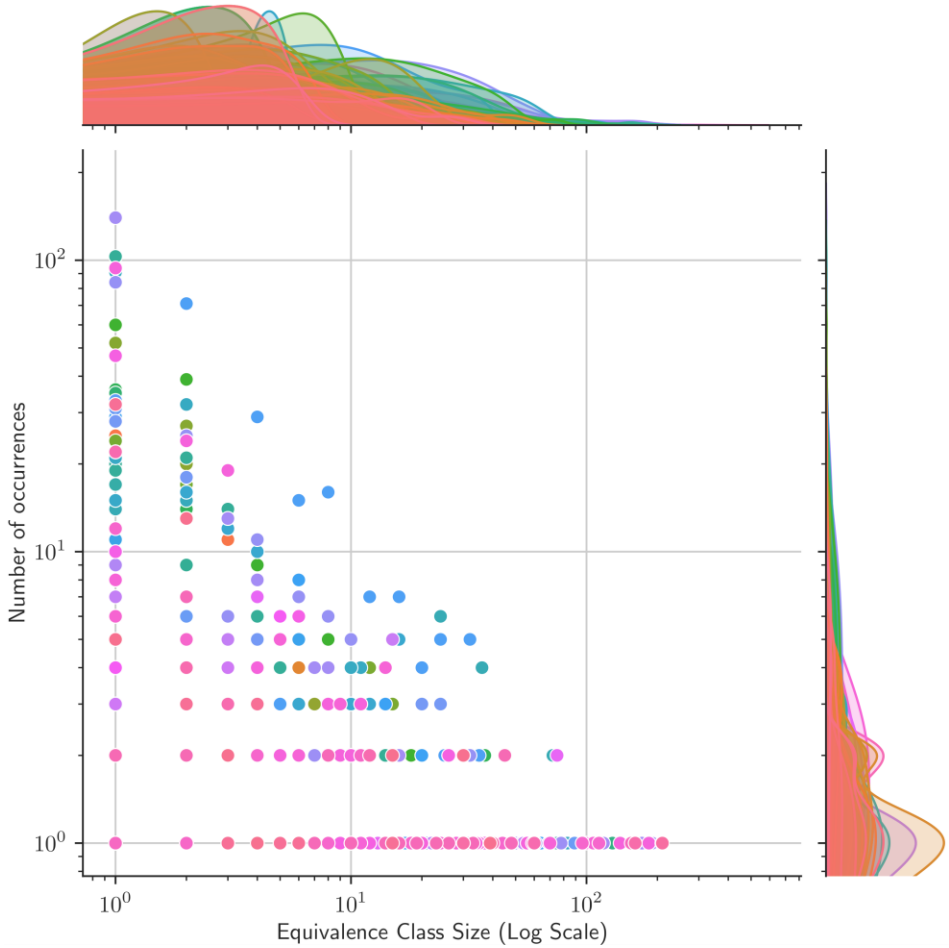


Equivalence Class Size Distribution

GSI 14

With dependencies & reachable

```
__cfi_slowpath(typeID,
               func_ptr);
```



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Takeaways

- Gap between schemes in practice and academia
- Android: Roll-out incomplete
- Equivalence class sizes look promising

In the paper

(eXtended) Control-flow Guard

Pointer Authentication

Branch Target Identification

CET Indirect Branch Tracking

CET Shadow Stack

The source code

https://github.com/seemoo-lab/woot24_cfi_coverage_tools/

References and Image Sources

[1]: MITRE, https://cwe.mitre.org/top25/archive/2023/2023_kev_insights.html#2023_kev_chart

Image Sources (by first appearances)

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